

The difference between existing steam turbine and the newest turbine

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law, Blade*

Abstract — *This article thoroughly analyzes the reasons for the low efficiency of existing steam turbine and, through a deep understanding and application of Betz's limit law and blade element momentum theory, redefines the efficiency of newest turbine.*

General introduction of Betz limit law.

All turbines (wind, steam, gas and all) follow Betz limit law. Because Betz limit is a mathematical law. The curve in fig 1 describes the efficiency of a single-disc rotor. The efficiency of rotor is higher when the TSR is between 5

and 10. The efficiency will quickly reduce when the TSR is away from 5 to 10. It means that only the blade tip area owns higher efficiency. Away from the blade tip, the efficiency of the rotor gradually decreases, and the efficiency is zero at the blade root.

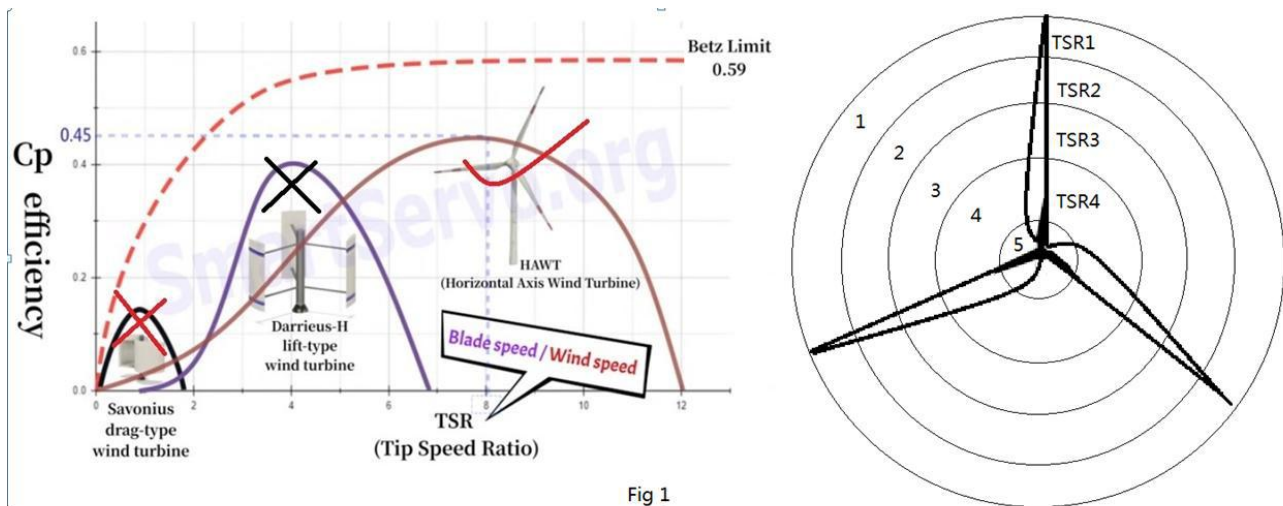


Fig 1

Betz Limit Law & TSR area

$TSR_1 > TSR_2 > TSR_3 > TSR_4$ as above fig 1. The TSR determines the rotor efficiency. According to Bernoulli's equation and calculation, finally we can obtain the results. The rotor efficiency is highest (59.3%) when the ratio of airflow speed before and after the rotor reaches $1/3$. The efficiency will be 56.3% when the ratio of airflow speed before and after the rotor reaches $1/2$. The efficiency will be 46.3% when the ratio of airflow speed before and after the rotor reaches $2/3$. The efficiency of area 1 is highest, the area 2 is lower than area 1, and area 3 is lower than area 2, the area 5 close to zero as fig1 because the reason for TSR decline..

The power (P) of a single-disc rotor shows as function, $P = (1/2) * k * \rho * S * V^3$. The k is the specific gravity of airflow, ρ is the efficiency of rotor, S is the area through the airflow passing, V is the speed of airflow. The airflow speed has the greatest impact on rotor power than k , ρ , S , and the k , ρ , S are fixed when the rotor has been designed.

Besides, most of existing wind turbine use three blades, but it does not means that three blades wind turbine owns highest efficiency instead of the power generation cost is lowest for three blades wind turbine.

From the perspective of the blade itself, a single-bladed rotor has the highest blade efficiency, but from the

perspective of the rotor, a single-bladed rotor has the lowest efficiency (the lowest power at same airflow speed). As a single-disc rotor, the rotor's efficiency with blades quantity, it follows <Rayleigh Distribution>. The relationship between rotor speed and the number of blades also follows a <Rayleigh Distribution>. A single-bladed rotor has the highest rotational speed. Increasing the number of blades improves the efficiency (power) of the rotor, but reduces the rotational speed. At a certain number of blades, the rotor efficiency (power) is maximized. Further increasing the number of blades will cause the rotor efficiency (power) to decrease, and when the number of blades reaches its limit (completely blocking the airflow), the rotor power becomes zero.

Blade Element Theory

The essence of blade element theory is to divide the blade into numerous small elements, assuming that each element is independent and does not influence the others. Local forces are calculated using two-dimensional airfoil data (such as lift coefficient and drag coefficient). This implies that the airflow direction specifically on the blade must be the same. From a local perspective, the direction of turbulence is chaotic, and the efficiency of turbulence acting on the lift-type airfoil will be reduced.

Defects of existing steam turbine.

Based on above knowledge, let us analysis existing rotors of steam turbine. Below is a rotor of steam turbine.

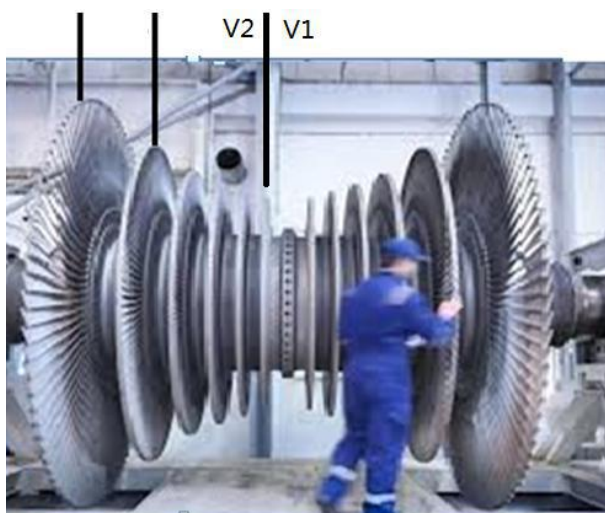
1. Multiple rotors share a shaft which is a typical coaxial structure. The rotors of the later stages reduce the

rotation speed of the first stage rotor.

2. The blade length is relatively long, extending from the rotor center to the blade tip.
3. Numerous blades quantity.



Steam turbine structure



Relation of rotors & airflow speed

The airflow speed from steam is V_1 , the airflow speed after rotor 1 is V_2 , and the airflow speed after rotor 2 is V_3 . The airflow speed is $V_1 > V_2 > V_3$. The power of rotor is $\text{rotor}_1 > \text{rotor}_2 > \text{rotor}_3$.

The rotors speed is the same between each rotors because the coaxial reason. But the V_1 is fast than V_2 and V_3 . The result is that TSR_1 of rotor₁ is lowest which can't reach 6-10. This is the reason, why the efficiency of rotor₁ is lower, but the rotor₁ owns highest kinetic energy, it can't be used and lost its efficiency. The energy changing of rotor₁ is the most important for the turbine. So, the Betz Limit Law does not show in existing steam/gas turbines

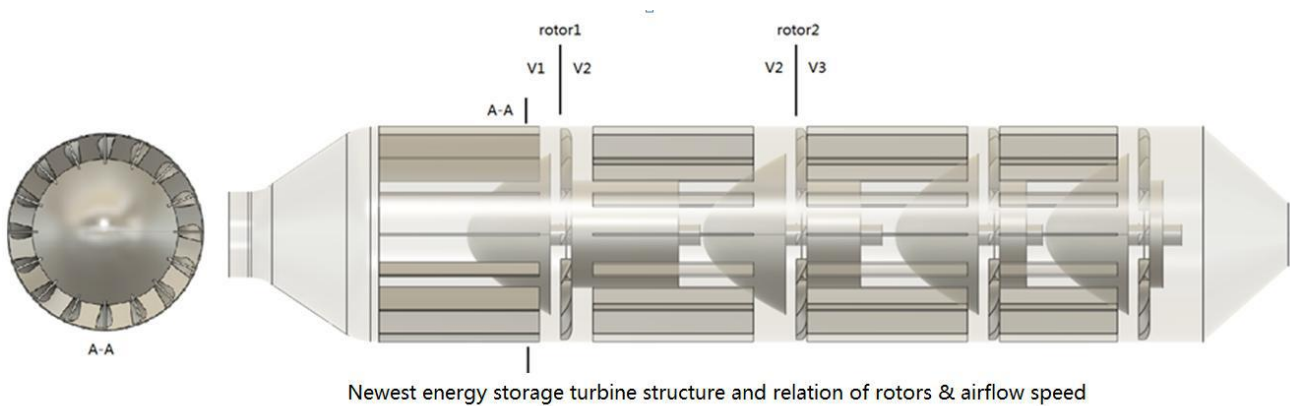
under existing steam/gas turbines solution.

Four core points of newest turbine

Based on blade element theory, and Betz limit law, the newest turbine four key points are:

1. In the airflow inlet, use deflectors smooth the airflow, reducing turbulence for keeping the same direction of airflow.
2. A diversion cover forces the airflow to pass only through the tip of the blades (area 1) and further increase the speed of airflow.
3. Independent rotor—each rotor drives its own generator which making the TSR of each rotor reaches 5-6.

4. Use lift-type rotor and reduce the blades quantity.



CONCLUSION

Based on the power function of rotor $P=(1/2)*k*\rho*S*V^3$

Each rotor power will be $P_n=(1/2)*k*\rho*S*V_n^3$.

Total power of the turbine is $P_t=P_1+P_2+P_3+P_4$.

As mention as above, the efficiency of each rotor is 56.3%

when V_2 is 1/2 of V_1 , $V_2=(1/2)V_1$, $V_3=(1/2)V_2$, then,

$$P_1=(1/2)*k*\rho*S*V_1^3,$$

$$P_2=(1/2)*k*\rho*S*((1/2)V_1)^3,$$

$$P_3=(1/2)*k*\rho*S*((1/2)*(1/2))V_1^3=(1/2)*k*\rho*S*(1/4)V_1^3$$

$$P_4=(1/2)*k*\rho*S*V_4=(1/2)*k*\rho*S*(1/8)V_1^3$$

$P_5=(1/2)*k*\rho*S*V_5=(1/2)*k*\rho*S*(1/16)V_1^3$, P_5 is output power if use four level rotors.

The turbine efficiency will be $1-(\text{output power} / \text{input power})=1-(P_5/(1/2)*k*\rho*S*V_1^3)$

$$=1-(((1/2)*k*\rho*S*(1/16)V_1^3)/((1/2)*k*\rho*S*V_1^3))=1-(0.563)*(1/16)/1=1-0.035=96.5\%,$$

The turbine theoretical efficiency will be 91% if the efficiency of generators reached 95% when the turbine uses 4 level rotors.

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